BELLCOMM, INC.
1100 Seventeenth Street, N.W. Washington, D. C. 20036

SUBJECT: Preliminary Weight Estimates for the Isotopic Brayton Cycle
Case 730

DATE: May 20, 1968

FROM: C. P. Witze

ABSTRACT

Weight estimates for the Radioisotopic Brayton Cycle being developed by NASA-Lewis are presented. Flight system weights are seen to range from 300 - 650 lbs/KWe for a 6.8 KWe unit depending upon the extent of future technological progress.

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MEMORANDUM FOR FILE

The Radioisotopic Brayton Cycle (RBC) is a leading candidate for the electrical power subsystem on-board a mid-seventies manned spacecraft. The purpose of this memorandum is to present weight estimates both for the RBC as it is now envisaged as well as a projected weight estimate reflecting possible technological advances that appear achievable in the near future.

Radioisotopic Brayton Cycle (RBC)

The Large Heat Source/Isotope Re-entry Vehicle (LHS/IRV) for the RBC has been discussed in a previous memo.[1] A schematic diagram of the LHS/IRV coupled to the Brayton Cycle energy conversion equipment is shown in Figure 1. Current designs[2] envision the fuel array as a slab radiating its thermal energy to the Brayton Cycle heat exchanger. The purpose of the re-entry body is to protect the fuel array during any normal or abnormal re-entry mode.

A preliminary design for the LHS/IRV is currently underway by AVCO for NASA-Lewis. The design is based upon an assembly of 2000°F, Plutonium-238 oxide fuel capsules with a total thermal output of 25 KWt. The Brayton Cycle rotating machinery is also being developed by NASA-Lewis and has a 1600°F turbine inlet temperature resulting in a nominal 6.8 KWe output. A tentative date for the coupling of the heat source to the energy conversion equipment for combined systems testing is 1971.

An estimated weight status for the RBC is indicated in Table 1. The column marked "current" represents a conservative weight estimate for the system as it now stands (shown in Figure 1) except for the waste heat radiator which can be incorporated into the spacecraft structural shell at relatively little weight penalty. The "improved current" column represents a modest design evolution to a flight-weight system. The column marked "design evolution" represents the effect of some important technological advances that could occur in time to influence the overall systems configuration by 1971. Total system weights are seen to range from 300-650 lbs/KWe for a 6.8 KWe system. Further elaboration on Table 1 follows.

LHS/IRV Weight Subtotal

The biggest single impact on the design of the LHS/IRV would be the early development of "vented" Pu-238 fuel capsules.[1] The basic idea involved in venting is to preferentially leak the helium gas generated by the alpha emitting fuel through a plug in the fuel capsule wall. Extreme care must be taken that plutonium and/or oxygen does not leave and/or enter the fuel capsule as well. In this way, the weight penalty associated with making each fuel capsule a high temperature pressure vessel for the collection of helium gas can be avoided. Estimates by the Oak Ridge National Laboratory indicate that the weight of the arrayed fuel capsules might drop as much as a factor of 2 to 4 if the venting problem can be solved satisfactorily.[2] Since the current LHS design involves about 160 capsules at 4.5 lbs apiece, the net savings on lighter fuel capsules alone might be in the neighborhood of 400 lbs.

The ability to construct a lighter and more compact fuel block assembly obviously results in lessened structural and re-entry protection requirements. Shadow shield weights also reduce considerably for smaller diameter heat sources. It should be pointed out, however, that a lower limit to the fuel block diameter could be dictated by (1) insufficient fuel capsule surface area for heat transfer to the heat exchanger or for emergency heat rejection, (2) potential criticality for such a compacted design, and (3) necessity of keeping frontal area large enough so that $W/C_D A$ is low and the chances of surface burial are minimal. If compact designs are acceptable from a safety viewpoint, then the requirement for sufficient heat transfer area to the Brayton Cycle equipment may require something like a convoluted heat exchanger penetrating an assembly of fuel capsules. Configurations of this type were investigated in a previous study[3] and were found to reduce IRV diameters and weights by at least 30%.

Power Conversion Unit (PCU) Package

The 1070 lb PCU package weight is based upon estimates from the prototype unit being assembled at NASA-Lewis.[4] The total PCU weight includes all turbomachinery, both heat exchangers, recuperator, ducting and insulation, controls, and gas management system. "Current" design philosophy is shown in Table 1 to require two mutually redundant PCU packages plumbed together. It is perhaps more reasonable to limit redundancy to failure susceptible components such as the rotating machinery. The weight savings incurred with this modus operandi are shown in the other two columns of Table 1.

A detailed breakdown of the PCU package weight is shown in Table 2. Batteries used for system startup and shutdown are not shown because their weight can be charged (or shared) with other subsystems on-board the spacecraft. The PCU package is sized to operate between 2.25 KWe and 10 KWe depending upon system pressure. As a result, the system components are oversized (and thus overweight) for any power requirement less than 10 KWe. Further weight reductions could eventually evolve through the replacement of the liquid heat rejection loop, for example, with heat pipes.

In summary, it should be pointed out that performance and weight characteristics of the RBC are continuously changing as NASA-Lewis gets more experience with the rotating machinery. It is clear, however, that significant weight reductions will occur if (1) vented fuel capsule technology is successfully developed and (2) replacement rather than redundancy is used to obtain reliability from the energy conversion equipment.

C. P. Witze

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C. P. Witze

Attachments

TABLE 1

RADIOISOTOPIC BRAYTON CYCLE WEIGHT STATUS

ITEM	CURRENT	IMPROVED CURRENT	DESIGN EVOLUTION
Fuel Block Assembly	1000	800	400
Re-entry Protection	400	350	200
Structure	100	100	75
Abort Rockets	130	130	105
Recovery Aids	70	70	70
LHS/IRV Subtotal (25 KWT)	1700 lbs.	1450 lbs.	850 lbs.
PCU Package	1070	1070	900
Extra PCU Unit	1070	---	---
Spare PCU Parts	---	300	240
Conversion Unit Subtotal	2140 lbs.	1370	1140 lbs.
Shield	600	600	200
TOTAL	4440 lbs.	3420 lbs.	2190 lbs.
Output 6.8 KWe			
Specific Weight	652 lbs/KWe	503 lbs/KWe	322 lbs/KWe

TABLE 2

POWER CONVERSION UNIT WEIGHT ESTIMATE

Component	Weight (lbs)
Structure, Latches, Disconnects	70
Brayton Rotating Unit (BRU)	140*
Heat exchangers, recuperator	520
Gas management system	90
Signal conditioner, speed regulator, controls,etc.	100*
Waste cooling system (liquid)	50
Insulation	100
Total PCU Weight	1070 lbs.

PCU packaging size: 33" x 55" x 66"

*Redundancy required.

Table 2 based on discussions with J. Klann, LeRC

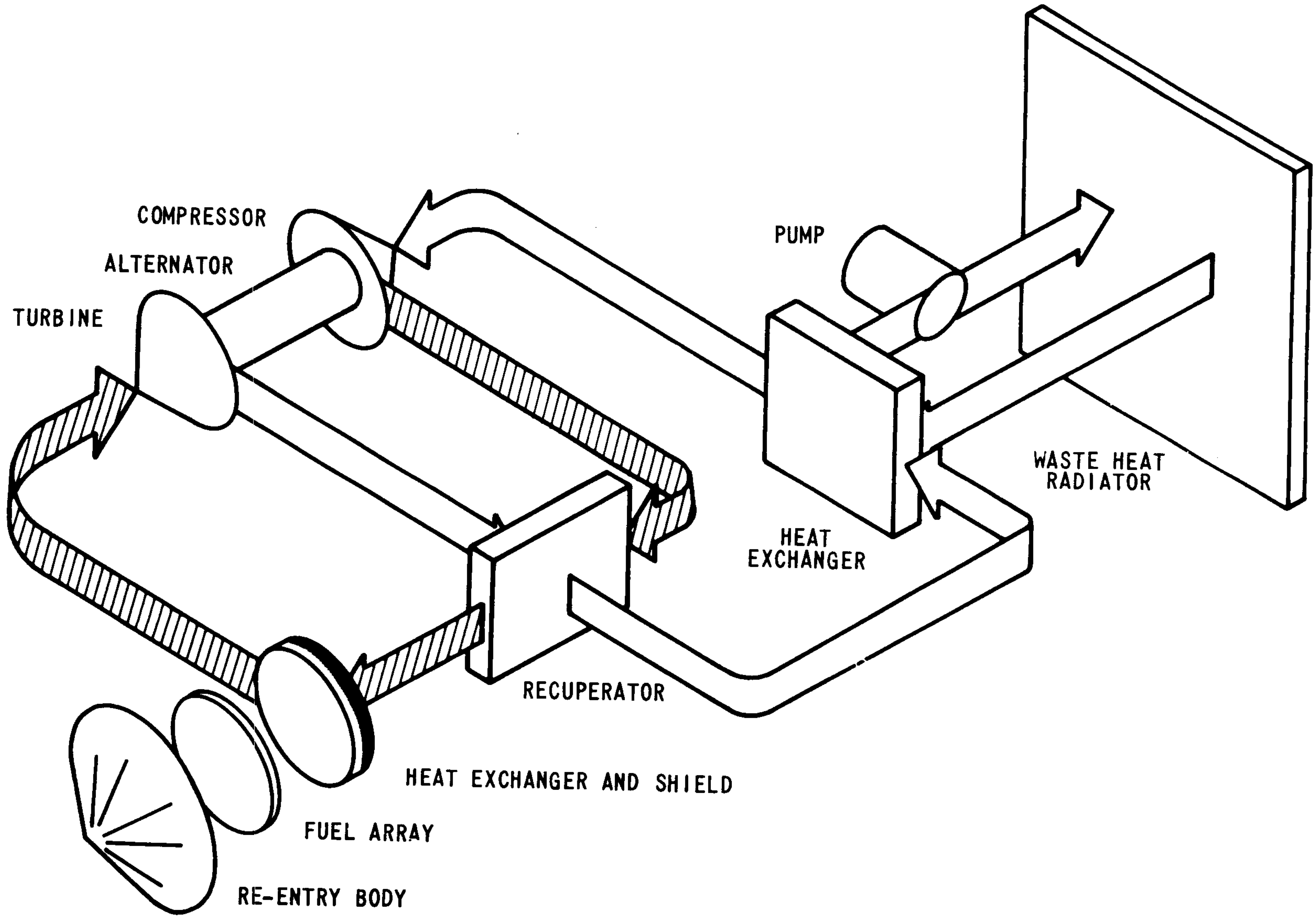

FIGURE I - RADIOISOTOPE/BRAYTON CYCLE

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3. Witze, C. P., "Possible Alternative Approaches to Isotope Re-entry Vehicle Design" Bellcomm Memorandum for File, May __, 1968.

4. Klann, J., private communication, April 25, 1968.